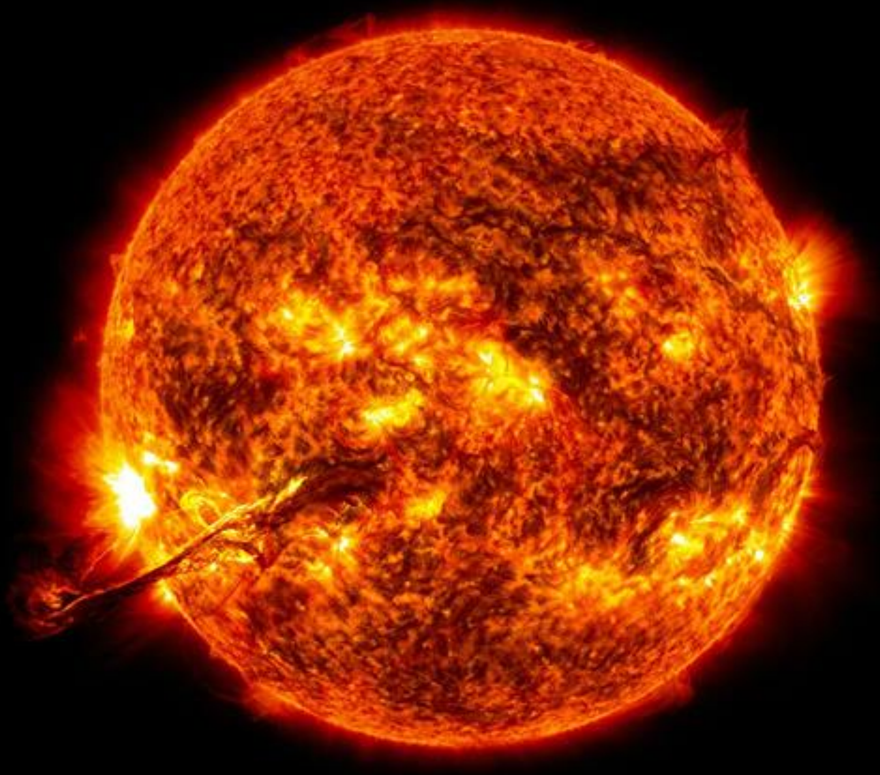
DEPARTMENT OF DEFENSE SPACE SCIENCE AND TECHNOLOGY STRATEGY 2015



Preparation of this report cost approximately $46,000

Distribution Statement A: Approved for Public Release; Distribution is Unlimited

Photo: Coronal mass ejection as recorded by NASA, August 31, 2014

U.S. Code Title 10, Subtitle A, Part IV, Chapter 135, Sec 2272 Space Science and Technology Strategy

(a) Space Science and Technology Strategy.—(1) The Secretary of Defense and the Director of National Intelligence shall jointly develop and implement a space science and technology strategy and shall review and, as appropriate, revise the strategy annually. Functions of the Secretary under this subsection shall be carried out jointly by the Assistant Secretary of Defense for Research and Engineering and the official of the Department of Defense designated as the Department of Defense Executive Agent for Space.

(2) The strategy under paragraph (1) shall, at a minimum, address the following issues:

(A) Short-term and long-term goals of the space science and technology programs of the Department of Defense.

(B) The process for achieving the goals identified under subparagraph (A), including an implementation plan for achieving those goals.

(C) The process for assessing progress made toward achieving those goals.

(D) The process for transitioning space science and technology programs to new or existing space acquisition programs.

(3) The strategy under paragraph (1) shall be included as part of the annual National Security Space Plan developed pursuant to Department of Defense regulations and shall be provided to Department of Defense components and science and technology entities of the Department of Defense to support the planning, programming, and budgeting processes of the Department.

(4) The strategy under paragraph (1) shall be developed in consultation with the directors of research laboratories of the Department of Defense, the directors of the other Department of Defense research components, and the heads of other organizations of the Department of Defense as identified by the Assistant Secretary of Defense for Research and Engineering and the Department of Defense Executive Agent for Space.

(5) The Secretary of Defense and the Director of National Intelligence shall biennially submit the strategy developed under paragraph (1) to the congressional defense committees every other year on the date on which the President submits to Congress the budget for the next fiscal year under section 1105 of title 31.

(b) Required Coordination.—In carrying out the space science and technology strategy developed under subsection (a), the directors of the research laboratories of the Department of Defense, the directors of the other Department of Defense research components, and the heads of all other appropriate organizations identified jointly by the Assistant Secretary of Defense for Research and Engineering and the Department of Defense Executive Agent for Space shall each—

(1) identify research projects in support of that strategy that contribute directly and uniquely to the development of space technology; and

(2) inform the Assistant Secretary of Defense for Research and Engineering and the Department of Defense Executive Agent for Space of the planned budget and planned schedule for executing those projects.

(c) Definitions.—In this section:

(1) The term “research laboratory of the Department of Defense” means any of the following:

(A) The Air Force Research Laboratory.

(B) The Naval Research Laboratory.

(C) The Office of Naval Research.

(D) The Army Research Laboratory.

(2) The term “other Department of Defense research component” means either of the following:

(A) The Defense Advanced Research Projects Agency.

(B) The National Reconnaissance Office.

Executive Summary

This report updates the 2013 Department of Defense (DoD) Space Science and Technology (S&T) Strategy. DoD space S&T organizations collaborate with and leverage the space S&T efforts performed by the Intelligence Community, the National Aeronautics and Space Administration, the Department of Energy, the National Oceanic and Atmospheric Administration, the commercial space industry and, as appropriate, Allied and friendly nations.

Significant accomplishments since the publication of the last report include new flexible solar cells at 34% efficiency enabling higher power spacecraft capability. These solar cells developed by the Air Force Research Laboratory (AFRL) are currently funded under MANTECH to transition in 2017. In addition, AFRL's Automated Navigation and Guidance Experiment for Local Space (ANGELS) satellite was launched in 2014. ANGELS hosts a sensor payload to evaluate techniques for detection, tracking and characterization of space objects, as well as attributions of actions in space.

Other success stories include the Hydrocarbon Boost demonstration that is developing domestic technologies for future medium-to-heavy lift launch systems. Also, AFRL's non-toxic monopropellant for spacecraft will be demonstrated in NASA's Green Propellant Infusion Mission in 2016.

This update of the DoD Space S&T Strategy was prepared with the assistance of the Reliance 21 Space S&T Community of Interest, a forum for sharing new ideas, technical directions and technology opportunities, jointly planning programs, measuring technical progress, and exchanging advances in space S&T.

DoD undertook a detailed review of critical future needs in multiple domains during the 2014 Strategic Portfolio Review. The decisions impacting the DoD Space S&T portfolio will be reflected in the next strategy update.

The DoD funded projects described in this report are fully consistent with the funding appropriated for DoD space S&T in FY 2013, FY 2014 or in the FY 2015 budget request.

> **We will continue to pursue, adapt, and evolve the unique technologies, innovative exploitation techniques, and diverse applications that give the United States its strategic advantage in space. The United States seeks to maintain and enhance access to those global and domestic technologies needed for national security space systems. We will do so by expanding technology partnerships with the academic community, industry, U.S. and partner governments, mission customers, and other centers of technical excellence and innovation, consistent with U.S. policy, technology transfer objectives, and international commitments. To advance the science and technology that enables U.S. space capabilities, we will continue to assess global technology trends to find emerging technologies and potential breakthroughs. We will explore new applications of current technologies and the development of unique, innovative technologies and capabilities. We will improve the transition of scientific research and technology development to the operational user and into major system acquisition. To the extent practicable, we will also facilitate the incorporation of these capabilities and technologies into appropriate domestic space programs.**
>
> ***– National Security Space Strategy***

Introduction

The Department of Defense (DoD) Space Science & Technology (S&T) Strategy guides the development of the space-unique technologies that are essential to maintain existing U.S. conventional and asymmetric military advantages enabled by space systems at the strategic, operational, and tactical levels. The U.S. Space Policy, National Security Strategy (NSS), Quadrennial Defense Review (QDR), and the National Security Space Strategy (NSSS) provide the strategic foundation for the DoD Space S&T Strategy. The Strategy is further informed by warfighter and Intelligence Community (IC) identified needs as expressed through Integrated Priority Lists (IPLs), Joint Urgent Operational Need (JUON) statements, current limitations in information collection and processing means, and identified future capability needs.

This strong foundation guides evaluations to determine: (1) which can be satisfied through modification of existing tactics, techniques, and procedures; (2) which can be satisfied through existing programs of record; (3) where developments in the commercial sector or performed by other Government agencies can be leveraged to meet DoD needs; and (4) those that can only be satisfied through the development of new capabilities. The DoD Space S&T Strategy focuses on providing those new capabilities through the development and maturation of technologies that will address unsatisfied needs, reduce risk in major acquisition programs, maintain technological superiority over potential adversaries, enable international cooperation, leverage commercial capabilities, avoid technological surprise, assist in maintaining a healthy and competitive space S&T industrial base, and mitigate vulnerabilities of space systems. The Strategy also supports critical themes from the NSSS of increased resilience, foreign cooperation, and use of hosted payloads.

DoD Space S&T, enabling new and improved space systems that meet these important challenges to our nation, will be performed in an environment that promotes cooperation,

collaboration, and partnership among all U.S. Government funded space S&T organizations, as well as foreign and commercial entities. A rigorous, comprehensive space S&T program, consistent with economic trends and budgetary constraints, ensures that the U.S. will continue to possess the distinctive advantages that space provides the DoD and the IC.

Methodology

This strategy has been prepared by the Office of the Assistant Secretary of Defense for Research and Engineering (OASD(R&E)) with the participation of the space S&T organizations within the Defense Components with input from the appropriate DoD research laboratories. Additionally, the National Reconnaissance Office (NRO) and the Office of the Director of National Intelligence provided advice and assistance. Final coordination was conducted with the DoD Executive Agent for Space Staff.

Senior representatives and technologists from the DoD Components participated in this collaborative process. Both the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) reviewed the draft strategy and provided information on S&T efforts they sponsor relevant to the identified goals. Their input has been incorporated into this update.

The information gathered was employed to update the short- and long-term goals in the 2013 report. Fourteen new S&T goals have been added, several to reflect the increased participation of NASA and NOAA in the preparation of the report. The descriptions for several goals have been modified to more accurately capture the essence of the projects in progress. The Appendix to the Strategy serves as a roadmap for the DoD space S&T community, detailing specific projects, metrics and timelines.

Additionally, in some cases goals appear as both short- and long-term to reflect that some portion of the capability will be achieved rapidly while the remaining elements require a longer development cycle. The methodologies employed to assess and monitor progress toward achievement of goals, and approaches to transition technologies to new or existing space acquisition programs are discussed in later sections.

Short- & Long-Term Space S&T Goals

The overarching objectives for national security space are: strengthening safety, stability, and security in space; maintaining and enhancing the strategic national security advantages afforded to the U.S. by space; and energizing the space S&T industrial base that supports U.S. national security. The DoD and the IC work together to achieve these objectives through five interrelated strategic approaches: promote responsible, peaceful, and safe use of space; provide improved U.S. capabilities; partner with responsible nations, international organizations, and commercial firms; prevent and deter aggression against space infrastructure that supports U.S. national security; and prepare to defeat attacks and to operate in a degraded environment. A robust and comprehensive space S&T program that maintains an appropriate balance between short- and long-term goals is a key element in achieving these objectives. Specific projects supporting the goals below are provided in Tables 1-9 in the Appendix.

Goals for Satellite Communications (SATCOM)

Short-term S&T goals:

- Reduce size, weight, power, cost, and improve thermal management for SATCOM terminals
- Support intelligence surveillance and reconnaissance (ISR) collection platforms
- Develop space-based laser communications for disadvantaged platforms and users
- Enable dedicated/theater controlled, space-enabled tactical communications in contested environments and diverse terrains
- Develop/enhance V-, W- and Ka-band radio frequency (RF) communications
- Develop spectrum sharing interference monitoring and prediction system for spacecraft telemetry, command & control (TT&C) functions

Long-term S&T goals:

- Develop/enhance V- , W-, and Ka-band RF, laser, and x-ray communications capabilities
- Enhance protection and resilience in contested environments
- Develop innovative and non-traditional TT&C technologies that are immune to interference
- Enhance space-based laser communications for disadvantaged platforms and users

Goals for Missile Warning, Missile Defense, Kill Assessment, and Attack Assessment (MW, MD, KA, & AA)

Short-term S&T goals:

- Improve sensors for whole earth staring
- Improve pre- and post-intercept algorithm capabilities for MD space-based sensors
- Improve data fusion algorithms for space-based MW, MD, KA, & AA capable sensors
- Improve automated analytic techniques for characterization and discrimination
- Develop prototype open architecture components and ground systems for current and future space-based MW, MD, KA, & AA sensors

Long-term S&T goals:

- Improve data fusion algorithms for space-based MW, MD, KA & AA capable sensors
- Develop fully integrated open architecture ground system for all current and future space-based MW, MD, KA & AA capable sensors
- Develop new sensor technologies to enhance characterization, discrimination of lethal objects and support KA
- Enhance post intercept assessment algorithms and databases using space-based MD capable sensors
- Improve ability to detect and track short range missiles under a wide range of conditions

Goals for Positioning, Navigation, and Timing (PNT)

Short-term S&T goals:

- Improve/enhance GPS anti-jam capabilities
- Improve atomic clocks for space systems
- Continue updating the IR celestial catalog
- Investigate robust alternative space-based navigation capabilities for GPS-degraded or denied environments
- Improve star tracker performance

Long-term S&T goals:

- Develop robust alternative space-based navigation capabilities for GPS-degraded or denied environments
- Complete update of the IR celestial catalog
- Enhance alternative orbital navigation technologies

Goals for Intelligence, Surveillance, and Reconnaissance (ISR)

Short-term S&T goals:

- Increase persistence and tactical responsiveness of space-based ISR
- Improve utilization of space assets through cross-cueing, integrated commanding, data product fusion, and tailored data distribution
- Improve integrated space-, air-, and ground-based ISR systems to enhance worldwide persistent coverage

Long-term S&T goals:

- Enable fully integrated space-, air-, and ground-based ISR systems to enhance worldwide persistent coverage
- Develop advanced tools to integrate data within a common reference framework
- Develop algorithms to identify activities of critical interest

Goals for Space Control (SC) and Space Situational Awareness (SSA)

Short-term S&T goals:

- Improve detection, characterization, conjunction, drag prediction, mitigation, and potential remediation of space objects
- Improve monitoring of potential space-based threats
- Develop technologies to increase protection and resiliency of space capabilities
- Develop technologies to increase cross-domain capabilities to enhance resilience
- Enhance SSA, including data processing
- Increase the capability to deter, inhibit, delay, or dissuade an adversary from impeding U.S. or Allied nation access to or use of the space domain
- Enhance the capability to maintain mission assurance in a degraded space environment

Long-term S&T goals:

- Achieve the capability to deter, inhibit, delay, or dissuade an adversary from impeding U.S. or Allied nation access to or use of the space domain
- Achieve the capability to maintain mission assurance in a degraded space environment
- Improve monitoring of potential space-based threats
- Achieve comprehensive knowledge of man-made orbital objects irrespective of size or location
- Develop robust SSA, including data processing
- Enable multiple simultaneous contacts to reduce logistics tail
- Develop active debris removal concepts

Goals for Space Access (SA)

Short-term S&T goals:

- Reduce launch cost and cycle time
- Develop more flexible launch operations and improved range safety technologies
- Develop responsive launch capabilities for small operational satellites
- Develop technologies to expand opportunities to employ commercial space assets
- Expand launch options for space experiments
- Develop higher performance on-orbit propulsion

Long-term S&T goals:

- Enable reduced cost, flexible, on-demand launch
- Develop technologies to enable fully reusable launch systems
- Develop technologies to further expand opportunities to employ commercial space assets

Goals for Space and Terrestrial Environmental Monitoring (EM)

Short-term S&T goals:

- Improve understanding and awareness of the Earth-to-Sun environment
- Improve space environment forecast capabilities and tools to predict operational impacts and enable real-time threat warning
- Improve space environmental sensors
- Improve marine meteorology and prediction using space assets
- Improve and enhance environmental monitoring of the Arctic region

Long-term S&T goals:

- Enhance space environment forecasting and enable real-time threat warning
- Improve accuracy of forecasting the geospace environment
- Enhance marine meteorology and prediction using space assets
- Develop comprehensive understanding and awareness of the Earth-to-Sun environment

Goals for Command and Control (C2) and Satellite Operations (SATOPS)

Short-term S&T goals:

- Increase autonomy for C2 systems to reduce manning
- Develop technologies enabling highly efficient on-orbit maneuvers and longer on-orbit life
- Increase space robotic capabilities with internal decision-making for on-orbit inspection, servicing, repair, assembly, harvesting subsystems, and life-extension
- Develop technologies supporting autonomous space systems

Long-term S&T goals:

- Enhance space robotic capabilities with internal decision-making for on-orbit inspection, servicing, repair, assembly, harvesting subsystems, and life-extension
- Achieve fully autonomous space systems

Goals for Space Enablers

Short-term S&T goals:

- Develop standardized and miniaturized components and interfaces for satellite buses and payloads
- Develop technologies to reduce costs and improve performance of satellite buses, payloads, and components
- Improve key building blocks for future responsive space systems
- Develop disruptive technologies enabling transformational space capabilities such as carbon-based nanotechnology
- Develop ultra-high-efficiency power system components, such as solar cells, batteries, and adaptive point-of-load converters
- Improve tools for design and test of components and systems
- Maximize satellite dry mass reduction through game-changing technologies
- Develop next generation space qualified focal planes

Long-term S&T goals:

- Improve ultra-high-efficiency power system components, such as solar cells, batteries, and adaptive point-of-load converters
- Maximize satellite dry mass reduction through game-changing technologies
- Develop technologies that facilitate integrating U.S. architectures with international and commercial partner systems and technologies
- Develop technologies that enable full autonomy across the spectrum of space system operations
- Develop generation-after-next component technologies enabling real-time data dissemination from national assets to small tactical units
- Develop high energy density/high power output power generation systems

- Develop simplified and accurate calibration/validation approaches for “staring” earth environmental monitoring instruments

Implementation

The Defense Components implement the DoD Space S&T Strategy as a routine element of their program planning and budgeting procedures. In this, consistent with the management and execution paradigm of Title 10, each Component has the primary responsibility to develop and conduct efforts that address their specific and, at times, unique mission responsibilities.

Thus, even while each Component may employ processes that are specifically tailored to their mission functions and organizational paradigms, all incorporate the same overarching fundamental elements. Longer-term strategic level goals and objectives are established based on guidance provided by U.S. Space Policy, the NSS, the QDR, the NSSS and the Defense S&T Strategy. Combatant Commander-identified needs, such as those provided by their S&T IPLs, inform these planning processes to develop more specific program-level goals and objectives. Additionally, insight gained from interchanges with industry, university researchers, Allies, and advisory panels assists in identifying additional technology shortfalls and opportunities that may merit pursuit.

ASD(R&E), in accordance with DoD Directive 5134.3, retains overall leadership and oversight responsibility for all DoD S&T. These responsibilities include, but are not limited to:

1. Developing the strategies and supporting plans that exploit technology and prototypes to respond to the needs of the Department of Defense and ensure U.S. technological superiority.
2. Conducting analyses and studies; developing policies; providing technical leadership, oversight and advice; making recommendations; and issuing guidance for the DoD Research & Engineering (R&E) plans and programs.
3. Recommending approval, modification, or disapproval of programs and projects of the Military Departments and other DoD Components in assigned fields to eliminate unpromising or unnecessarily duplicative programs, and initiation or support of promising ones for R&E.

The combination of these enables each responsible S&T organization to establish realistic short-term project plans and long-term vectors to guide their technology development activities. In technology areas where multiple organizations sponsor activities, interagency coordinating councils, roadmaps, and technical interchanges are employed to facilitate coordination between Components as well as with other federal agencies such as NASA and NOAA.

Under the Reliance 21 framework, ASD(R&E), through the S&T Executive Committee (S&T EXCOM), recently created a Space S&T Community-of-Interest (COI). During the past year it has been developing coordinated roadmaps to further strengthen cross-Component coordination and collaboration.

There are many other mechanisms employed to foster collaboration and coordinate efforts. These include: the Air Force-NASA-NRO Summit; NRO-USSTRATCOM Summit; Navy-NRO Summit; the IC Space Board (provides all IC space stakeholder awareness of and an opportunity to shape IC positions on contemporary space positions); the NRO Technology Forum; the Joint DoD-NASA-US-Industry Rocket Propulsion for the 21st Century Program; the Joint Army-Navy-NASA-Air Force Inter Agency Propulsion Committee; the Joint Space Team; the NRO Space Pillars Meeting (a collaborative forum that investigates key space technology and process issues with participation from across the IC and DoD); the DoD Space Experiments Review Board; and the NASA-NRO Working Group Meetings.

In addition, both the Air Force and the Navy provide representatives to the Federal Committee for Meteorological Services and Supporting Research, chaired by the Office of the Federal Coordinator for Meteorology (OFCM), and the inter-Agency National Space Weather Program, that is coordinated by the OFCM. Additionally, the Joint Center for Satellite Data Assimilation is a partnership between NOAA, NASA, the Navy, and the Air Force dedicated to developing and improving the ability to exploit environmental monitoring data for terrestrial weather forecast models and applications.

DoD also continues to aggressively pursue international collaborative efforts with our Allies and other friendly nations. Bi-lateral and multi-lateral agreements enable the DoD space S&T program to pursue collaborative efforts to explore innovative concepts being developed in the international community as well as to benefit from the technical expertise that exists in other countries. There are currently 38 MOUs/MOAs, 52 Active Data/Information Exchange Agreements with 20 Countries and 46 Active Project Agreements with 13 Countries. Examples include: the US/UK Defense Science and Technology Space Communiqué on Space Technologies that builds on an existing strong relationship to address emerging priorities. In addition, several domestic and international DoD collaborative space missions are ongoing, for instance: the ESA/NASA Solar Orbiter mission that will launch in 2017, carrying onboard the NRL-led, NASA-funded SoloHI (Solar Orbiter Heliospheric Imager) instrument that will obtain time-lapse imagery of solar coronal mass ejections and the evolving solar corona from within the orbit of Mercury.

It is important to note that significant informal coordination and collaboration at the Subject Matter Expert (SME) level occurs between DoD scientists and engineers and their counterparts in other federal agencies, Academia, and the defense and commercial space industry through participation in domestic and international professional conferences. These forums, which enable our SMEs to interact with their colleagues on an individual basis, are critical for their professional development as well as the advancement of S&T to the mutual benefit of the defense, civil and commercial space sectors.

Progress metrics and transition plans also are identified as part of the Component project-level planning process. These provide the timelines, achievement milestones, and intended transitions to system applications that become an integral element of the Component S&T investment philosophy. Memoranda of Understanding are employed in some cases to provide formal agreements to transition S&T products into either proposed acquisition programs or existing operational systems.

Space-related S&T development activities are performed through a variety of methods. Some projects are conducted within Service laboratories. The Defense Advanced Research Projects Agency (DARPA) and the Missile Defense Agency (MDA) employ a variety of methods to execute their space S&T projects. These approaches include, at times, utilizing government laboratories, traditional and non-traditional industry sources under efforts awarded in response to Broad Agency Announcements and other solicitations, Small Business Innovation Research solicitations, sponsorship of Federally Funded Research and Development Centers (FFRDC) and University Affiliated Research Centers (UARC), cooperative efforts with other federal agencies such as NASA and the Department of Energy (DOE), as well as collaborative efforts with Allies and other nations when appropriate.

Assessment

Assessment reviews to measure and monitor progress towards achievement of goals are conducted at various levels throughout DoD S&T organizations. These include working level assessments at the project and program level; reviews at the Component laboratory, organizational and headquarters levels; reviews by independent advisory boards; cross-organizational review forums; and reviews at the Agency Director or Service and DoD Assistant Secretary level. In select cases, the Deputy Secretary of Defense (DSD) may be asked to adjudicate issues that cannot be resolved at lower levels.

These reviews may include the participation of Combatant Commands, Component headquarters, laboratory directors, peer review boards, and advisory councils. On-going and proposed activities are evaluated to ensure that they are consistent with strategic guidance and identified short- and long-term warfighter needs, while still providing adequate opportunities to explore potentially disruptive or transformational technologies. In select instances, special panels of outside experts may be established to review specific program objectives and technical status for capabilities needed for particular missions.

Component level reviews are conducted in a manner consistent with the mission and operating paradigm of each organization. Project and program performance with respect to cost, technical achievements, and schedule progress are evaluated in both periodic structured and informal programmatic and technical reviews.

The Army, for example, employs reviews by the Army Science and Technology Working Group and the Army Science and Technology Advisory Group as part of its internal review process. The Office of Naval Research (ONR) and the Naval Research Laboratory (NRL) conduct annual reviews of applied research and advanced technology development within various portfolios and biennial reviews of basic research. Annually, a joint overall Investment Balance Review of the entire Navy S&T portfolio is performed.

For the Air Force, yearly S&T reviews are conducted by the Commanders of the Air Force Space Command (AFSPC), the Air Force Research Laboratory (AFRL), and the Air Force Space and Missile Systems Center (AF SMC). The Deputy Assistant Secretary of the Air Force (Science, Technology & Engineering) also conducts a separate annual S&T review. In addition, the Air Force Office of Scientific Research conducts annual reviews of its basic research portfolio

including Space Science, Physics and Astronomy, and Space Propulsion and Power, engaging the public, Government, Industry and Academic scientific and User communities. Finally, the Air Force Scientific Advisory Board (AF SAB) conducts biennial reviews of the AFRL S&T Portfolio, and the Air Force Chief Scientist regularly assesses progress in space S&T.

Warfighter Technical Councils and Acquisition Program Executive Office reviews also may be conducted when appropriate. Space-related Advanced Technology Demonstrations are reviewed yearly at the Applied Technology Council held as part of the Space S&T Council.

When appropriate, recommendations for program or funding adjustments can be submitted for review by the ASD(R&E) S&T EXCOM. ASD(R&E) is the S&T EXCOM chair with the Component S&T Executives as the principal members. Through cross-Component coordination, the S&T EXCOM strengthens the overall effectiveness and efficiency of the Department's R&E investments in areas which cannot be addressed adequately by a single component.

Finally, the DSD, during the DoD annual program review cycle, may be asked to adjudicate those questions and issues that cannot be resolved in lower level reviews. These issues can include reallocating funding, authorizing major shifts in program focus, approving new initiatives, as well as eliminating efforts that are underperforming or no longer required.

Transition

Planning for transition is an integral part of the DoD Space S&T Strategy. Although space S&T programs have some unique attributes compared to other types of S&T efforts, there is no single distinctive process for transitioning space S&T products. Instead, transition processes are tailored to the nature of the technology being developed and eventual application.

For a wide variety of component technologies, such as radiation hardened microelectronics, solar cells, electric thrusters, and batteries, the S&T projects develop the next generation of components and conduct the necessary ground-based or space-based testing to verify performance and suitability. Once these activities have been completed, the component is then available as an "off-the-shelf item," which the vendor can then provide in response to solicitations from prime or lower-tier contractors. For example, in 2013, AFRL developed new flexible solar cells at 34% efficiency, enabling higher power spacecraft capability. These solar cells developed by the Air Force Research Laboratory (AFRL) are currently funded under MANTECH to transition in 2017.

The Advanced Inertial Measurement Unit (AIMU) began as an AFRL High Visibility Program in 2008 with the objective of modernizing navigation capabilities for strategic systems including future ICBM/SLBM, bombers and cruise missiles. AIMU has drawn the attention of numerous prime contractors interested in transitioning the AIMU technologies into their baseline concepts for a future Ground Based Strategic Deterrence program. Additionally, this is the first time that component strategic grade accelerometers and gyroscopes possess the reliability, low size, weight and power and radiation hardness needed for space missions applications with potential transition in the 2018-2020 timeframe.

Joint Capability Technology Demonstrations (JCTD) provide another approach to assess innovative technologically mature capabilities and determine military utility that can facilitate transitioning to operational status. JCTD emphasis is on technology integration and assessment rather than technology development. JCTD demonstrations are jointly sponsored by operational users and the materiel development communities.

Some technology programs obtain critical phenomenological data acquired from space experiments. The Near Field Infrared Experiment (NFIRE) is an example of this type of S&T experimental mission. Algorithms, analysis techniques, and models created using such data are transitioned into acquisition activities by the government and industry specialists and designers in those programs.

Proof-of-principle or proof-of-concept demonstrations provide another path for transition. The Space Tracking and Surveillance System-Demonstrators (STSS-D) are excellent examples. STSS-D provided critical detection and launch quality tracking data to enable an Aegis Ballistic Missile Defense (BMD) system launch on remote test. This demonstrated the fully calibrated performance of each satellite, its crosslink systems, and the acquisition and track sensor payloads.

AFRL's Communications/Navigation Outage Forecast System (C/NOFS) continues to provide valuable data for validating sensor designs, data exploitation and algorithm development for space situational awareness environmental monitoring. C/NOFS data has been used for the AFSPC Space-Based Environmental Monitoring (SBEM) Analysis of Alternatives (AoA) to evaluate the military utility of space-based data in assessing the operational impact of equatorial scintillation. The C/NOFS data also is being exploited to better understand the phenomenology of the ionosphere.

AFRL's TacSat-3 completed flight test and was deorbited. The flight data are being used to assess the operational utility of Hyperspectral Imaging data. AFRL conducted a final experiment with the TacSat-3 spacecraft to test the limits of the sun exclusion zone for optical payloads before de-orbiting the spacecraft.

The Joint Space Operations Center (JSpOC) Mission Systems (JMS) program currently monitors tens of thousands of space objects. Increment 1, reported in the 2013 DoD Space S&T Strategy, was transitioned to operational use in 2013. Increment 1 provides: a net-centric service oriented infrastructure; a modern, graphical user interface for operating the space fleet; the foundational infrastructure for all future development; and over 80 SSA and command and control applications. The development of Increment 2 is also being supported by AFRL. Specifically, the laboratory is supporting the design of increment 2 as well as the development of satellite breakup processing capability, the determination of the space order of battle capability and further developments of the infrastructure, such as the User Defined Operating Picture. Increment 2 is on track for implementation in FY16 and increment 3 in on track for implementation in FY17.

As noted above, some technologies must be tested or demonstrated in space to verify and validate performance to support transition. The DoD Space Test Program (STP), created in

1965, supports on-orbit test and experimentation for those organizations not otherwise authorized to conduct space flight. STP has been an essential enabler for integration and launch resources and executing the DoD's Space Experiment Program by providing payload integration, launch, and on-orbit operation services. Through FY14, STP provided space flight for 228 missions hosting 549 experiments**.** Many of those experiments have laid the groundwork for operational military space systems such as GPS, Milstar, and the Defense Meteorological Satellite Program.

On some occasions, space system acquisition programs have facilitated the transition of new technologies by providing "ride-along" opportunities. These are typically employed to support their technology maturation and risk reduction activities. Space flight opportunities provided by other U.S. Government agencies, Allied nations, and commercial satellite systems also have been employed to conduct DoD space S&T experiments and demonstrations.

Funding

The DoD funded projects included in this strategy represents a program of work fully consistent with the funding appropriated in FY 2013, FY 2014 or in the FY 2015 budget request.
This funding is sufficient to pursue the high priority S&T efforts identified by processes including the DoD Combatant Commands IPLs, S&T IPLs, JUONs and the ASD(R&E) recommendations on S&T priorities to the Secretary of Defense for incorporation in the DoD S&T planning guidance.

Human Capital and Infrastructure

Adequacy of Human Capital and Infrastructure – Air Force:

Every two years, the Air Force Scientific Advisory Board (AF SAB) reviews one-half of the portfolio for each of the nine directorates within AFRL and assesses the technical quality, relevance to near-term Air Force needs, potential impact to mid-and far-term Air Force capabilities and utilization of funding, workforce and facility resources. Space technology development is performed in eight of the nine directorates with the bulk of it within three directorates: AFRL Space Vehicles for satellite technology, AFRL Aerospace Systems for launch vehicle technology, and AFRL Directed Energy for research primarily using ground-based telescopes to support SSA. The ground-based optical SSA and space weather areas have consistently been rated as world-class. The AF SAB has not identified any specific shortfalls in human capital that would detrimentally impact execution of AFRL's space S&T portfolio.

The AF SAB also reviews the adequacy of AFRL's facilities, determining that the current facilities range from adequate to world class and can meet Air Force S&T needs. AFRL has two facilities capable of fully integrating and testing small experimental satellites. One of these facilities is used primarily for unclassified payloads while the other is for classified payloads. These facilities are shared with the DOE Sandia National Laboratory. The military construction program also is employed when existing space infrastructure facilities need to be upgraded or when new facilities are required to satisfy emerging needs.

Adequacy of Human Capital and Resources Including Infrastructure – Navy:

The Navy possesses the necessary personnel and facilities to execute its space S&T program. A report was provided on 19 September 2014, based on an external review of in-house NRL space research. This report noted that the program, “is clearly functioning at the level of a world-class laboratory as envisioned by Thomas Edison to support Navy and Marine Corps needs. The RC was extremely impressed with the dedication, skill, and ingenuity of all the NRL personnel involved with the [program]. The scientists and engineers of the [program] are among the best that one would find at a top tier research university. NRL has provided a vibrant working environment and state-of-the-art research and technology facilities that have attracted and retained top notch personnel. There is also a healthy mix of experienced and early career scientists and engineers that ensures the vitality of the laboratory, while maintaining strong leadership over its mission. ... [T]he research laboratories of the [program] are comprehensive and very well equipped. The laboratory infrastructure is self-contained, and both support personnel and equipment are maintained at a sufficiently robust level to allow researchers to accomplish tasks in a timely manner while maintaining the flexibility to respond quickly to new Navy and Marine Corps challenges." Subsequently, NRL has a unique capability to fully integrate, conduct pre-launch testing and post-launch operation of spacecraft as well as perform subsequent data analysis.

The NRL space S&T program is evaluated internally annually with respect to the following criteria: Technology Readiness Level increase; overall S&T objectives; accomplishments and achievements; in-house and external relationships, and research standing; research documentation and external recognition; and, scientific payoff, and potential for transition. NRL space RDT&E objectives are coordinated across the broader ONR S&T program and in collaboration with other DoD, national, and international stakeholders, notably including the NRO and the Defense Intelligence Agency. The goal is to design and build research payloads and capabilities at a relatively modest cost that benefit Navy and wider DoD space needs. Efforts to date have led to significant STP-enabled achievements such as: 1. The invention of the foundations for GPS; 2. The initial discovery and follow-on research on the operational impacts of solar coronal mass ejections and space experimental research of geospace (a basis for the Air Force Weather Agency (AFWA) operational Global Assimilation of Ionospheric Measurements); and 3.The robust remote sensing capabilities such as WindSat that have proven invaluable for tropical cyclone forecasting transitioned to the operational Navy.

Adequacy of Human Capital and Infrastructure – Army:

The Army space S&T program is modest in relation to the efforts performed by the Air Force and the Navy. The Army has determined it has a sufficient cadre of trained personnel to execute its current space S&T programs. However, the Army recognizes it would need to increase staffing levels should its program of work increase substantially.

The Army space S&T program employs infrastructure and facilities to Redstone Arsenal, Marshall Space Flight Center, Army facilities in Colorado Springs, as well as other DoD and DOE laboratories and Industry. This network of infrastructure and facilities is more than adequate to enable the Army to execute its current portfolio of space S&T projects.

Adequacy of Human Capital and Infrastructure – DARPA and MDA:

Neither DARPA nor MDA maintain their own laboratory systems. As noted previously, DARPA and MDA execute their space S&T programs through a variety of sources. These sources can include sponsoring programs at the DoD and DOE laboratories, contracts with Industry, efforts performed by Universities and UARCs, placing work with NASA Research Centers or FFRDCs, in cooperative programs with other federal government organizations, and, when appropriate, collaborative projects with Allied and friendly nations. Their execution approach ensures that adequate infrastructure and human capital will be available to support their space S&T efforts.

Success Stories

The C/NOFS program includes a dedicated equatorial satellite to measure the properties of the ionosphere; a network of ground-based sensors to measure scintillation and space-to-ground total electron content; and a data center that assimilates the data from the satellite and ground sensors into models of the ionosphere, forecasts the state of the ionosphere, and assesses which regions of the ionosphere are likely to cause scintillation problems. In addition to serving as the pathfinder for space situational awareness environmental monitoring and providing key data for the SBEM AoA, the C/NOFS program is the centerpiece of on-going efforts to develop, validate and transition state-of-the-art forecasting models of the space environment to AFWA, JSpOC, the Global SATCOM Support Center (GSSC), and other operational users. AFRL provides a user-specific scintillation nowcasting product to the GSSC for their use in electro-magnetic interference resolution. C/NOFS has spawned a revolution in the understanding and modeling of the equatorial ionosphere.

Communications/Navigation Outage Forecasting System *(*C/NOFS*)*

AFRL's Automated Navigation and Guidance Experiment for Local Space (ANGELS) satellite was successfully launched in August 2014 and is currently undergoing on-orbit checkout and calibration. ANGELS hosts an SSA sensor payload to evaluate techniques for detection, tracking, and characterizing of space objects, as well as attribution of actions in space. This includes demonstrating safe, automated resident space object rendezvous, proximity operations and inspection and a high-data rate laser downlink. ANGELS also demonstrated the EELV Secondary Payload Adaptor (ESPA) Standard Service on an operational mission.

TacSat-4 completed its S&T goals demonstrating communications-on-the-move capabilities. Before it ceased operations in February 2014, it provided substantial utility by augmenting geostationary SATCOM coverage for high latitudes and for blue-force tracking in under-served areas. TacSat-4's dynamic reallocation capability showed that such a system could provide rapid, flexible communications augmentation in dense RF and interfered environments.

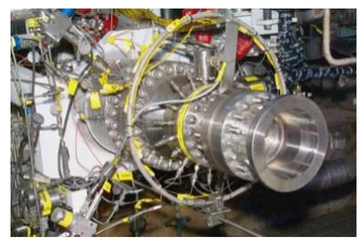
Tactical Satellite-4 (TacSat-4)

Green Propellant Infusion Mission (GPIM)

AFRL developed a new non-toxic monopropellant, AFM 315E, that will be flight tested in 2016 under the collaborative NASA-AFRL Green Propellant Infusion Mission (GPIM). This "green" fuel reduces handling hazards for personnel and offers the advantages for future satellites of increased fuel efficiency and a nearly 50 percent higher performance than hydrazine.

The NRL Virtual Mission Operations Center (VMOC) demonstrated web-enabled, multi-application secure satellite services for approved users without requiring any man-in-the-loop involvement. VMOC includes orbital mechanics and satellite models that greatly improve utilization efficiency. Currently VMOC is being used operationally for the Operationally Responsive Space (ORS)-1 satellite and is being certified for the mission planning of OPIR assets. Other programs have expressed interest in using VMOC following certification for the OPIR mission.

Under their Future Naval Capability, Detection and Fusion of Remote Sensors, ONR has successfully demonstrated prototype algorithms for processing operational data that enable operational tasking by the Fleet. This improves the use of space assets through cross-cueing, integrated commanding, fusion of data products and tailored data distribution.



Hydrocarbon Boost Technology Demonstrator (HCB)

The Hydrocarbon Boost (HCB) demonstration project is developing domestic technology for future medium-to-heavy lift launch systems. The project is nearing completion of the early technology risk reduction to inform full-scale technology demonstration and component design of an oxygen rich staged combustion cycle engine. The current sub-scale pre-burner activity provides the necessary ignition and propellant flow condition knowledge. It also validates oxygen rich gas mixing and thermal management design approaches. Finally, the individual component and integrated engine demonstrator data will be used to validate and anchor recently developed advanced physics based liquid rocket engine modeling and simulation tools.

Space Test Program Satellite 3 (STPSat-3)

As part of the ORS-3 mission, Space Test Program Satellite 3 (STPSat-3) was successfully launched in November 2013 with six experiments and 28 cubesats, The experiments included: iMESA-R (Integrated Miniaturized Electrostatic Analyzer Reflight), a U.S. Air Force Academy mission designed to measure plasma densities and energies; J-CORE (Joint Component Research), a space phenomenology mission sponsored by AFRL and Army SMDC; SSU (Strip Sensor Unit), an AFRL experiment to provide risk reduction through on-orbit testing and operation of a sensor assembly; SWATS (Small Wind and Temperature Spectrometer), an NRL mission to provide in-situ measurements of the neutral and plasma environment to characterize the Earth's ionosphere and thermosphere; and Total Solar Irradiance (TSI) Calibration Transfer Experiment (TCTE), a NASA/NOAA mission to collect high accuracy, high

precision measurements of TSI to monitor changes in solar irradiance incident at the top of the Earth's atmosphere.

Between 2010 and 2013, the U.S. Army Space and Missile Defense Command – Orbital Nanosatellite Effort (SMDC-ONE) placed five 3U cubesats into orbit. These five satellites represented the first Army-developed spacecraft to be deployed into orbit in over 50 years. Designed to demonstrate communications and data exfiltration for disadvantaged tactical users, the satellites exceeded their mission requirements. They have paved the way for small follow-on tactical communications and ISR satellites being developed to responsively provide data to the ground component warfighter.

SMDC-ONE 3U Cubesat

Army SMDC has been participating with OSD, PACOM, Army PEO Missiles & Space, NASA, and industry on a JCTD called Soldier-Warfighter Operationally Responsive Deployer for Space (SWORDS). This JCTD has been focused on the development of technologies that could lead to a small, low cost, tactically responsive space launch system. In September 2014 SWORDS successfully hot-fire tested a 60,000 pound thrust first stage rocket engine; the largest Liquid Oxygen-Liquid Methane engine ever successfully tested in the U.S. Most significantly, the engine was constructed of commercial-off-the-shelf components and technologies, and represents a design with a unit recurring cost approaching one dollar per pound of thrust.

In November 2013, the Space and Naval Warfare Systems Command (SPAWAR) and U.S. Special Operations Command (USSOCOM)-led Vector JCTD launched two nano-satellites demonstrating advanced communications capabilities. The multi-mission bus design is being evaluated for future use in Navy and Joint projects.

Summary

The DoD Space S&T Strategy guides the development of the space-unique technologies that are essential to maintaining U.S. conventional and asymmetric military advantages enabled by space systems at the strategic and tactical levels. It is developed in concert with national defense policy and strategy, and is informed by warfighter and IC identified needs as expressed through IPLs, JUONs, current limitations in information collection and processing means, and identified future capability needs. The DoD Space S&T Program continues to provide a pathway to develop, demonstrate, and transition advanced capabilities to acquisition programs and warfighters.

The DoD Space S&T Strategy focuses on providing new capabilities through the development and maturation of technologies that will address unsatisfied needs, reduce risk in major acquisition programs, maintain technological superiority over potential adversaries, enable international cooperation, leverage commercial capabilities, avoid technological surprise, assist in maintaining a healthy and competitive industrial base, and mitigate vulnerabilities of space systems. The Strategy fosters collaboration among all S&T organizations, including foreign and

commercial entities, responsible for space technology development. It has been successful in defining and accomplishing important space S&T goals.

Appendix – GOAL AND PROJECT TABLES

Table 1 Satellite Communications

Short Term S&T Goals	Technology Focus	Project Name	Service/Agency	Completion	Key Metric
Reduce size, weight, power, cost, and improve thermal management for SATCOM terminals	Compact laser comm terminal	Compact Laser Terminal (COLT)	AF-AFRL	FY 16	Space flight demo
Support ISR Collection Platforms	Downlink laser comm	Automated Navigation and Guidance Experiment for Local Space (ANGELS-SSA)	AF–AFRL	FY 16	Space flight demo
Develop space-based laser communications for disadvantaged platforms and users	Laser comm ground station	Compact Laser Terminal (COLT)	AF-AFRL	FY 16	Space flight demo
	Laser comm	Optical Communications and Sensor Demonstration (OCSD)	NASA	FY16	Demonstrate laser comm from cubesats
	Laser comm	Deep Space Optical Communication (DSOC)	NASA	FY17	Photon counting, sensitivity increased by 10x
	Laser comm	Laser Comm Relay Demonstration (LCRD)	NASA	FY 19	Laser comm from GEO
Enable dedicated/theater controlled, space enabled tactical communications in contested environments and diverse terrains	Comms/data exfiltration nanosatellite	SMDC Nanosatellite Program (SNaP) JCTD	Army-SMDC	FY 15	Up to 56 kbps, 250 simultaneous text message users and data exfiltration

Table 1 Satellite Communications, cont'd

	Low probability of detection encryption system suitable for laser comm to LEO satellite	Secure Comms	AF-AFRL	FY 17	Space flight demo
Develop/enhance V-, W- and Ka - band radio frequency (RF) communications	Ka band data downlink	Integrated Solar Array and Reflectarray Antenna for High Bandwidth CubeSat (ISARA)	NASA	FY 15	3U cubesat Ka band system – 100 mbps downlink goal
	Ka band reflectarray	Integrated Solar Array and Reflectarray Antenna for High Bandwidth CubeSat (ISARA)	NASA	FY 15	Integrated Solar Array and Ka band antenna
	Ka-band tactical comms	Advanced Smallsat Communications Technologies	Army-SMDC	FY 17	Space flight demo
Develop spectrum sharing interference monitoring and prediction system for spacecraft telemetry, command & control (TT&C) functions	Develop TT&C systems that mitigate threats resulting from loss of spectral bands and bandwidth	Spectrum Monitoring System	NOAA	FY 17	Matured to support deployment to USG systems
Long Term S&T Goals	**Technology Focus**	**Project Name**	**Service/Agency**	**Completion**	**Key Metric**
Enhanced space-based laser communication for disadvantaged platforms	Laser comm	Optical Payload for Laser comm Science	NASA	Ongoing	Demonstrate laser comm from ISS
Develop/enhance V-, W- and Ka - band radio RF communications	Increase bandwidth capability and flexibility	Future Space Communications	AF-AFRL	FY 20	Space flight demo

Table 1 Satellite Communications, cont'd

Enhanced protection and resilience in contested environments	Increase bandwidth capability and flexibility	Future Space Communications	AF-AFRL	FY 20	Space flight demo

Table 2 Missile Warning, Missile Defense, Kill Assessment and Attack Assessment

Short Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Improve sensors for whole Earth sensing	Focal plane development	Protection for Visible and Near Infrared ISR Sensors	AF-AFRL	FY 15	Transition to acquisition
	Improved visible & infrared sensor chip assemblies (SCAs)	Advanced Electro-Optical Space Sensors for ISR	AF-AFRL	FY 17	Transition to acquisition
	Data collection and analysis for future space-based systems	Space Tracking and Surveillance System Demonstrators (STSS-D)	MDA	Ongoing	Space flight demo
Improve pre- and post-intercept algorithm capabilities for MD space-based sensors	Develop and improve algorithms and databases for intercepts	Remote Optical Characterization of Kinetic Intercept (ROCKI)	MDA	FY 17	Demo prototypes in flight tests
	Data collection and analysis for intercept assessment	Remote Optical Characterization of Kinetic Intercept (ROCKI)	MDA	Ongoing	Flight Tests and Targets of Opportunity
	Real-time intercept assessment	System for Post Engagement Evaluation and Reporting (SPEER)	MDA	FY 17	Demo prototypes in flight tests
	Exploitation of Space-based Sensors	BMDS OPIR Architecture (BOA)	MDA	FY 17	Multiple prototype demos
Improve data fusion algorithms for space-based MW, MD, KA & AA capable sensors	Develop algorithms for new OPIR data	C2BMC ESL Experimentation and Deployment of Algorithms to Utilize Space Based Infrared System (SBIRS) GEO Scanner/Starer Sensors	MDA	FY 17 (GEO Scanner); FY 20 (GEO Starer)	Space flight demo

Table 2 Missile Warning, Missile Defense, Kill Assessment and Attack Assessment, cont'd

	Data fusion tools	Multivariate Data Fusion and Uncertainty Quantification for Remote Sensing	NASA	FY15	Provide formal measures of uncertainty associated with data fusion output
	Maintain track on maximum number of targets for fire control, cueing and guidance optimization	Sensor Resource Management	MDA	FY 14	Improved performance algorithms
	Exploitation of Space-based Sensors	BOA	MDA	FY 19	Ground and Flight Test
Improve automated analytic techniques for characterization and discrimination	Advanced missile characterization and typing	Overhead Persistent Infrared Rapid Advanced Characterization from Launch to Engage	MDA	FY 14	Space flight demo
	Data fusion	Sensor Data Fusion	MDA	FY 14	Improved performance algorithms
	EO/IR sensor to discriminate between debris and countermeasure in a dense scene	Multi-Spectral Countermeasure and Debris Identification and Mitigation	MDA	FY 14	Improved performance algorithms
	Detect missile launch under a wide range of weather conditions	Signature Exploitation	AF-AFRL	FY 17	Space flight demo

Table 2 Missile Warning, Missile Defense, Kill Assessment and Attack Assessment, cont'd

	Data collection and analysis for future space-based systems	Space Tracking and Surveillance System Demonstrators (STSS-D)	MDA	Ongoing	Space flight demo
Develop prototype open architecture components and ground systems for current and future space-based MW, MD, KA, & AA sensors	Real-Time Transfer Service (RTS) – Joint OPIR Ground (JOG)	Enterprise Sensors Lab (ESL) RTS Integration	MDA	Ongoing	Multiple prototype demos
	Planning and Tasking	Automated Responsive Global Observation System (ARGOS)	MDA	FY 17	Multiple prototype demos
	Real-Time Transfer Service (RTS) – Joint OPIR Ground (JOG)	BOA	MDA	FY 19	Ground and Flight Test
Long Term S&T Goals	**Focus**	**Project Name**	**Service/Agency**	**Completion**	**Key Metric**
Improve data fusion algorithms for space-based MW, MD, KA & AA capable sensors	Atmospheric transmission algorithms	Imaging Spectroscopy	AF-AFRL	FY 20	Space flight demo
Develop fully integrated open architecture ground system for all current and future space-based MW, MD, KA & AA capable sensors	Real-Time Transfer Service (RTS) – Joint OPIR Ground (JOG)	C2BMC	MDA	FY 21	Ground and Flight Test
	Data collection and analysis for intercept assessment	Remote Optical Characterization of Kinetic Intercept (ROCKI)	MDA	Ongoing	Flight Tests and Targets of Opportunity

Table 2 Missile Warning, Missile Defense, Kill Assessment and Attack Assessment, cont'd

	Real-time intercept assessment	System for Post Engagement Evaluation and Reporting (SPEER)	MDA	FY 21	Ground and Flight Test

Table 3 Positioning, Navigation, and Timing

Short Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Improve/enhance GPS anti-jam capabilities	Integrated military anti-jam (AJ) antenna systems with small footprint using both GPS navigation and Iridium communication satellite signals.	GPS-Iridium Anti-Jam (AJ) Antenna Systems for Air and Sea Platforms	SPAWAR, NAWCWD	FY 16	Field test/demo
Improve atomic clocks for space systems	Compact precision molecular clock	Advanced Laser Frequency Stabilization	NASA	FY 15	Space flight demo
	Mercury-ion trap technology	Deep Space Atomic Clock	NASA	FY 17	Improve data quality by 10X; Improve clock stability by 100X
	Low SWaP atomic clock	Cold Atom	AF-AFRL	FY 17	Space flight demo
	Compact atomic clock	Development of a Compact Space Optical Clock for Tests of Fundamental Physics	NASA	TBD	Compact space optical clocks based on single trapped ions
Continue updating the IR celestial catalog	Ground based telescope observations	USNO Robotic Astrometric Telescope (URAT)	USNO	FY 17	accuracy goal of 5-30 milliarc-seconds
	Atmospheric interferometer	Navy Precision Optical Interferometer (NPOI)	USNO	FY 19	accuracy of ~ 10 milliarc-seconds

Table 3 Positioning, Navigation, and Timing, cont'd

Investigate robust alternative space-based navigation capabilities for GPS-degraded or denied environments	Gyroscope based inertial guidance system	Fast Light Optical Gyroscope for Precision Navigation	NASA, Army-AMRDEC	FY 16	Field test/demo
	Advanced inertial guidance technology	Strategic Systems and Launch Technologies	AF-AFRL	FY 17	Transition to operational use
	X-ray receiver for timing and navigation	Station Explorer for X-ray Timing and Navigation Technology (SEXTANT)	NASA, NRL, AFRL, NRO, NIST	FY 18	Space flight demo
	Anti-jam enhancement for GPS assured reception	High Integrity GPS (HiGPS)	Navy-NRL	FY 18-19	Transition to operational use
	Chip based cold atom gyroscope	Cold Atom	AF - AFRL	FY 19	<10m/hr drift
Improve star tracker performance	Star tracker	Precision High Altitude Star Tracker Project (PHAST)	NASA	FY 14	Open source balloon flight demo to reduce cost and complexity
Long Term S&T Goals	**Focus**	**Project Name**	**Service/Agency**	**Completion**	**Key Metric**
Develop robust alternative space-based navigation capabilities for GPS-degraded or denied environments	Low-cost GPS adjunct	Advanced GPS technologies	AF-AFRL	FY 20	Space flight demo
	Nav & timekeeping GPS alternative in space	Astrophysical Clocks and X-ray Navigation	Navy–NRL	FY 25	Simulation of space-based x-ray pulsar navigation and timing capability

Table 4 Intelligence, Surveillance, and Reconnaissance

Short Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Increase persistence and tactical responsiveness of space- based ISR	Small, disposable, low cost constellations for persistent ISR	SeeMe	DARPA, Army-SMDC, AMCOM	FY 14	Ground demo
	Wirelessly-interconnected space craft modules for secure resource sharing	System F6	DARPA, NASA, Navy-NRL	FY 14	Software and designs
	Learning framework to classify data	An Advanced Learning Framework for High Dimensional Multi-Sensor Remote Sensing Data	NASA	FY15	Software tools to help analyze remote sensing data
	Fusion algorithms for "A-train" satellite data	Global Modeling and Assimilation Office	NASA	Ongoing	Space flight demo
Improve utilization of space assets through cross-cueing, integrated commanding, data product fusion and tailored data distribution	Tools to coordinate asynchronous distributed missions	EPOS for Coordination of Asynchronous Sensor Webs	NASA	FY15	Software tools to optimize Earth observations
	Improved detection, cross-cueing, fusion and tailored distribution of data products	Detection and Fusion of Remote Sensors	Navy-ONR	FY 17	Operational Demo
Improve integrated space-, air-, and ground-based ISR systems to enhance worldwide persistent coverage	Tactical imaging spacecraft	Kestrel Eye JCTD	Army-SMDC	FY 16	Launch call up to satellite imagery in < 48 hrs

Table 4 Intelligence, Surveillance, and Reconnaissance, cont'd

Long Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
	Advanced tactical imaging spacecraft	Kestrel Eye III	Army-SMDC	FY 17	Space flight demo
Enable fully integrated space-, air-, and ground-based ISR systems to enhance worldwide persistent coverage	Detect high interest materials, facilities, and activities in denied areas from space	Imaging Spectroscopy	AF-AFRL	FY 20	Actionable intelligence

Table 5 Space Control and Space Situational Awareness

Short Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Improve detection, conjunction, drag prediction, mitigation and potential remediation of space objects	Conjunction prediction & orbit trajectory propagation tools	High Performance Computing Software Applications Institute for Space Situational Awareness (HSAI-SSA)	AF-AFRL	FY 15	Demo
	Laser-based tracking of orbital debris	Ground-based Laser Ranging for ID and Tracking of Orbital Debris	NASA	FY 15	Space flight demo
	Resolve GEO-belt space objects	Space Object Surveillance	AF-AFRL	FY 15	Resolve objects in < 10 min
	Ground-based optical detection and tracking of faint deep space objects	Space Surveillance Telescope (SST)	DARPA	FY 17	Ground demo
Improve monitoring of potential space-based threats	Collaborative space information fusion	Space Domain Awareness (SDA)	DARPA	FY 16	Ground demo
	Image resident space objects (RSOs)	Automated Navigation and Guidance Experiment for Local Space (ANGELS)-SSA	AF-AFRL	FY 16	Space flight demo
	Timely LEO imaging of dim LEOs and LEO-GEO CSO detection	Characterization Enhancement Using Adaptive Objects	AF-AFRL	FY 16	Dim object imaging
	Daylight characterization of objects	Advanced Characterization Techniques (ACT)	AF-AFRL	FY 16	Daylight imaging
	Detect, track and assess threats	Spacecraft Awareness Sensors	AF-AFRL	FY 17	Integrated sensor suite
	Imaging of GEO objects	Long Range Imaging LADAR	AF-AFRL	FY 18	Tech demo
	Improve sky surveillance coverage using next-gen optics & photonics	Advanced Technologies for Extreme Conditions (ATEC)	AF-AFRL	FY 18	Testing of next-gen adaptive objects

Table 5 Space Control and Space Situational Awareness, cont'd

	Daylight monitoring of GEO objects, dynamic tasking of sensors, astrodynamics	Satellite Object Custody	AF-AFRL	FY 19	Networking of telescopes
	Deep space imagery, change detection research & anomaly identification	High Power Electro-Magnetics (HPEM) for Space Superiority	AF-AFRL	FY 19	Space flight demo
Develop technologies to increase protection and resiliency of space capabilities	Spacecraft ID/characterization	SSA Integration Group – Multi-sensor Exploitation for Space Situational Awareness (MESSA)	AF-AFRL	FY16	Correlation of pre- and post-launch measurements
	Detect, track and assess threats	Spacecraft Awareness Sensors	AF-AFRL	FY 17	Integrated sensor suite
	Space object ID/characterization	Space Fusion, Assessment & Characterization for Threat Prediction (Space FACT)	AF-AFRL	Ongoing	Increase warning time/reduce analysis time
Develop technologies to increase cross-domain capabilities to enhance resilience	Optical downlink	Integrated Optical Communications and Proximity Sensors Demonstration (OCSD)	NASA	FY 15	Demonstrate optical comm from LEO
	Integrate all-source info with new observations to identify & characterize space objects	EO Integration & Innovation Center	AF-AFRL	Ongoing	Transition to operational use
Enhance SSA, including data processing	Automated threat detection/response	Decision Support Systems – Space Situation Awareness Fusion Intelligent Research Environment/Joint Space Operations Center Mission System (SAFIRE/JMS)	AF-AFRL	FY 16	Space flight demo

Table 5 Space Control and Space Situational Awareness, cont'd

	Ground-based optical detection and tracking of deep space objects	Space Surveillance Telescope (SST)	DARPA, USNO	FY 17	Ground demo
	Reduce space object tracking error	Guidance, Navigation and Control	AF-AFRL	FY 17	80% reduction track error
	Low-cost smallsat for GEO SSA	SensorSat	AF-AFRL	FY17	Space flight demo
	Space-generated ground force nanosat tasking and control	Space Tactical Processing, Exploitation & Dissemination (TPED) Demos	Army –SMDC	FY 19	Distributed Common Ground System – Army (DCGS-A) Interface Demos
Increase the capability to deter, inhibit, delay, or dissuade an adversary from impeding U.S. or Allied nation access to or use of the space domain	Proof-of-concept for HAND remediation	Radiation Belt Remediation, Demonstration and Science Experiment (DSX) - Flight	AF-AFRL	FY 18	Space flight demo
	Proof-of-concept for HAND remediation	Innovative NanoSat Flight Experiment Series	AF-AFRL	FY 18	Space flight demo
	Space collision risk reduction	Elimination of Space Debris via Drag	Navy–NRL	FY 18	Demo of suborbital dust-based active debris removal
	Collision avoidance predictive tools	Cloud Dynamics of Satellites	Navy–NRL	FY 19	Demo of orbit determination & satnav with probabilistic modeling and drag software

Table 5 Space Control and Space Situational Awareness, cont'd

Long Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Enhance the capability to maintain mission assurance in a degraded space environment	Assess threats, model, design and test satellite protection concepts	Satellite Vulnerability & Protection	AF-AFRL	FY 18	Transition to operational use
	Radiation displacement damage effects	Realtime Radiation Displacement Damage	Navy–NRL	FY 18	Tech demo with prototype low SWaP-C device
Long Term S&T Goals	**Focus**	**Project Name**	**Service/Agency**	**Completion**	**Key Metric**
Achieve the capability to deter, inhibit, delay, or dissuade an adversary from impeding U.S. or Allied nation access to or use of the space domain	Near-space radiation effects characterization	Terrestrial Gamma-ray Flashes (TGFs)	Navy–NRL	FY 20	Demo of TGF radiation signatures estimator
	Near-space radiation effects characterization	Terahertz (THz) Observations	Navy–NRL	FY 23	Demo next-gen THz optical components for detection of special nuclear material
Improve monitoring of potential space based threats	Development of a space weather anomaly portal to predict effects of space weather events on satellites	Space Weather Anomaly Portal	NOAA	Ongoing	Sufficient data to populate reliable forecast models
Achieve comprehensive knowledge of man-made orbital objects irrespective of size or location	Spacecraft interferometric imaging techniques	Imaging with the Naval Precision Optical Interferometer (NPOI)	Navy-NRL	FY 20	Space flight demo

Table 6 Space Access

Short Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Reduce launch cost and cycle time	Spinning slosh testing on SPHERES satellites	Dedicated Slosh Dynamics Experiment on ISS using Synchronized Position Hold Engage and Reorient Experimental Satellites (SPHERES)	NASA	FY 14	Test
	Cryogenic loading system monitor	Autonomous Systems Project: Autonomous Cryogenic Loading Operations Project (ACLO)	NASA	FY 15	Test
	Acoustic suppression	Lightweight High Performance Acoustic Suppression (HiPAcS) Technology Development	NASA	FY 15	Test
	Orbital transport for nanosatellites	Nanolauncher Technologies Initiative	NASA	FY 15	Launch of <50kg payload
	Low cost, persistent and responsive space access	Experimental Spaceplane1 (XS-1)	DARPA	FY 15	Preliminary Design
	Space Technology	Overcoming Low Nozzle Efficiency	Navy-NRL	FY 15	Space experiment demo
	Enable low-cost secondary payloads	Flight Experiment – EAGLE	AF-AFRL	FY 16	Space flight demo
Develop more flexible launch operations and improved range safety technologies including autonomous flight safety systems	Nanosatellite launcher	Soldier-Warfighter Operationally Responsive Deployer for Space (SWORDS)	NASA, Army-SMDC	FY 14	Engine demonstration
	Air launch system	Air Launch from a Towed Glider	NASA	FY 14	More economical, increased payload, safer

Table 6 Space Access, cont'd

	Electromotance shielding system	A Novel Electromotance Noise Mitigation System	NASA	FY 14	Shields from EM noise with high density electron fields
	Integrated air-breathing and rocket engine	Reusable Military Space Launch Concepts Study (COI Seedling)	AF-AFRL	FY 15	Characterize design sensitivities
	Fiber optics strain gauge for launch vehicles	Fiber Optic Sensing Systems for Launch Vehicles	NASA	FY 16	Reduce sensor system mass to 1% or less
	Small satellites launched from an airborne platform to LEO	Airborne Launch Assist Space Access (ALASA)	DARPA, NASA	FY 16	Space flight demo
Develop technologies to expand opportunities to employ commercial space assets	On-orbit technologies	Propulsion Unit for CubeSat	AF-AFRL	FY 16	Space flight demo
	On-orbit propulsion	High Power Electric Propulsion	AF-AFRL	FY 18	Space flight demo
	Broker shared rides for scientific and tech-demo payloads	NASA GSFC Payload Rideshare Program	NASA	Ongoing	Rideshares
Develop responsive launch capabilities for small operational satellites		Increase Opportunities Through Space Test Program (STP)	DoD Space S&T Community	Ongoing	
Expand launch options for space experiments	Expendable launch system	Super Strypi - Spaceborne Payload Assist Rocket-Kauai (SPARK)	OSD, AF-ORS	FY 15	Launch

Table 6 Space Access, cont'd

Develop higher performance on-orbit propulsion	Liquid propulsion	Advanced Liquid Propellant	AF-AFRL	FY 16	70% performance improvement
	Adjustable nozzle	Altitute Compensating Nozzles	NASA	FY 14	10% payload benefit
	"Green" fuel	Green Propellant Infusion Mission (GPIM)	NASA	FY 16	Space flight demo
Long Term S&T Goals	**Focus**	**Project Name**	**Service/Agency**	**Completion**	**Key Metric**
Enable reduced, cost, flexible, on-demand launch	Liquid propulsion	Hydrocarbon Boost	AF-AFRL	FY 20	Brassboard demo

Table 7 Space and Terrestrial Environmental Monitoring

Short Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Improve understanding and awareness of the Earth-to-Sun environment	Coronal mass ejection impacts	Advanced Radiation Protection (includes ISEP Project and MC-CAD Analysis)	NASA	FY 14	Fielding of analysis tools
	Chemical tracer to explore upper atmosphere	Investigation of Anomalous Transport in the Lower Thermosphere	NASA	FY 14	Help model the electromagnetic regions of space that can damage satellites
	Models of ionization and recombination	Laboratory Measurements of Electron Impact Ionization in Support of the NASA Heliophysics Research Program	NASA	FY 14	Understand ionization effects for iron ions
	Measure MEO space environment	Flight Experiment – DSX	AF-AFRL	FY 16	Flight experiment
	Solar wind measurements	Deep Space Climate Observatory (DSCOVR)	NASA	FY 15	Space flight demo
	Hazardous spacecraft charging early warning	Spacecraft Plasma Diagnostic Suite	Navy-NRL	FY 15	Demo prototype spacecraft charging probe
	Extend magnetohydrodynamic models of solar activity to improve comm and mag impact prediction	Tracing the Origins of the Solar Wind	Navy-NRL	FY 18	Transition to operational use
	Hazardous S/C charging early warning	Spacecraft Plasma Diagnostic Suite	Navy-NRL	FY 18	Space flight demo
	Extended operational environment (EOE): heliospace characterization	Integrating the Sun-Earth System	Navy–NRL	FY 19	Transition to operational use

Table 7 Space and Terrestrial Environmental Monitoring, cont'd

Improve space environment forecast capabilities and tools to predict operational impacts and enable real-time threat warning	Space environment alerts software	Space Environment Automated Alerts and Anomaly Analysis Assistant (SEA^5)	NASA	FY 14	Unprecedented awareness and understanding impacts on mission
	Solar spectroscopy instrument	U.S. Participation in the Solar Orbiter Multi Element Telescope for Imaging and Spectroscopy (METIS)	NASA	FY 16	Key insights for predicting the occurrence of extreme space environmental conditions
	Spacecraft attitude and environment sensing	Ram Angle & Magnetic Field Observations	Navy-NRL	FY 18	Demo prototype low SWaP-C sensor suite for a PicoSat
	EOE: heliospace characterization	Spectroscopic Techniques for Space Wx	Navy–NRL	FY 19	Demo next-gen EUV spectroscopic space-borne instrument
	Forecast agent for NASA's robotic missions	Space Weather Research Center	NASA	Ongoing	Space flight demo
	EOE: heliospace characterization	Non-linear Excitation of Space Plasmas	Navy-NRL	FY 19	Space flight demo of artificial ionospheric layer generation
	EOE: heliospace characterization	Thermospheric Wind Instrumentation	Navy-NRL	FY 19	Demo next-gen thermosperic winds space-borne instrument

Table 7 Space and Terrestrial Environmental Monitoring, cont'd

Improve space environmental sensors	Next generation imaging sensor for temporal and spatial resolution of ionosphere	Limb-Imaging Ionospheric and Thermospheric Extreme-Ultraviolet Spectrograph (LITES)	Navy-NRL	FY 14	Space flight demo
	Extended operational environment characterization	Ground-based Round-the-Clock Auroral Observations	Navy-NRL	FY 15	Transition for operational use
	Web-based analysis tools	Integrated Space Weather Analysis (iSWA) System	NASA	Ongoing	Transition to operational use
Improve marine meteorology and prediction using space assets	Development of soil moisture retrieval algorithm	WindSat	Navy–NRL	FY 18	Transition to operational use
	Aerosol observation, prediction and understanding	Exploitation of Satellite Data for Characterization of the Environment	Navy–NRL	FY18	Transition to operational use
	Generate global atmospheric analysis fields	Atmospheric Navy Global Environmental Model (NAVGEM)	Navy–NRL	FY18	Transition to operational use
	Improve prediction of tropical cyclones	Coupled Ocean-Atmospheric Mesoscale Prediction System – Tropical Cyclone (COAMP-TC)	Navy–NRL	FY18	Transition to operational use
Improve and enhance environmental monitoring of the Arctic region	Develop capabilities or leverage those of allies, to monitor the weather and climate in the Arctic regions	Satellite Architecture Studies - Partnership with Canada on the Polar Communications and Weather satellite program	NOAA, AFWA, USAF	Ongoing	Launch of a satellite system to meet requirements and needs for Arctic climate and weather

Table 7 Space and Terrestrial Environmental Monitoring, cont'd

Long Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Improve space environment forecasting and enable real-time threat warning	EOE: geospace characterization	Whole Atmosphere Ionosphere Modeling	Navy–NRL	FY 20	Transition to operational use
	Solar energetic particle (SEP) characterization	Seed Populations for Large SEP Events	Navy–NRL	FY 21	Demo numerical model of high-energy SEP and solar gamma ray emissions
	Advanced space weather instruments	Space Particle Hazards Specification and Forecast	AF-AFRL	FY 22	Transition tools and components for operations
	Space forecast tools	Ionospheric Impacts - Space Weather Forecasting Laboratory (SWFL)	AF-AFRL	FY 22	Transition to operational use
	Ionosphere models and mission impact	Ionospheric Impacts - SSA/ISR	AF–AFRL	FY 22	Transition to operational use
	Neutral density and wind forecast	Ionospheric Impacts - Orbital Drag	AF-AFRL	FY 22	Transition to operational use
	Coronal mass ejection models	Solar Disturbance Prediction	AF-AFRL	FY 22	Transition to operational use
Enhance marine meteorology and prediction using space assets	Ocean and coastal measurement	GEOstationary Coastal and Air Pollution Events (GEO-CAPE) – (Part of NASA Decadal Survey Program)	NASA	FY 20	Technology demo

Table 8 Command and Control and Satellite Operations

Short Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Increase autonomy for C2 systems to reduce manning	Autonomous control algorithms	Autonomous Flocking and Cooperative Control of Multi-Vehicle Systems	NASA	FY 15	Autonomous cooperative control of multi-vehicle systems
	Autonomous navigation technologies	Advanced Multi-Mission Operations Systems (AMMOS) Technology	NASA	Ongoing	Technology to support autonomous planetary science mission
Develop technologies enabling highly efficient on-orbit maneuvers and longer on-orbit life	Improved rendezvous and proximity operations (RPO) performance	Guidance, Navigation and Control	AF-AFRL	FY 17	GEO GPS position determination
Increase space robotic capabilities with internal decision-making for on-orbit inspection, servicing, repair, assembly, harvesting sub-systems and life-extension	Robotic technology development	Human Robotic Systems (HRS)	NASA	FY 14	Demo on extreme terrain testbed
	Robotic capture mechanisms, end effectors and tools	Human Robotic Systems (HRS): Robotic Technologies for Asteroid Missions	NASA	FY 14	Technologies support in-space assembly and construction, satellite servicing and repair

Table 8 Command and Control and Satellite Operations, cont'd

Long Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
	Validate robotic operations for repairing, assembling, and reconfiguring satellites	Phoenix	DARPA, NASA Navy -NRL	FY 16	Space flight experiment
	Robotic satellite servicing	In-Space Robotic Servicing (ISRS)	NASA	FY 19	Space flight demo
Develop technologies supporting autonomous systems	Advanced spacecraft computing	High Performance Spaceflight Computing (HPSC)	NASA, AFRL	FY 14	100x improvement in processor performance
	Spacecraft propulsion	Space Plasma EM Lab Investigation	Navy-NRL	FY 19	Laboratory chamber demo
Long Term S&T Goals	**Focus**	**Project Name**	**Service/Agency**	**Completion**	**Key Metric**
Enhance space robotic capabilities with internal decision-making for on-orbit inspection, servicing, repair, assembly, harvesting sub-systems and life-extension	Tactical space robotics	Robotic Tactile Sensing and Mobility for Detection	Navy-NRL	FY 22	Demo of robotic tactile constrained-environment and mobility capabilities
Acheive fully autonomous systems	On-board autonomous system to operate through anomalies and threats	Decision Support Systems – Autonomous Ops	AF-AFRL	FY 20	Technology demo
	Spacecraft propulsion	Enabling Technologies for EM Vehicle	Navy-NRL	FY 21	Space flight demo

Table 9 Space Enablers

Short Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Develop standardized and miniaturized components and interfaces for satellite buses and payloads	Avionic standards	Avionics Architecture for Exploration Project	NASA	FY 14	Standardize avionics for 80% of components
	ASIC for miniaturized instruments	A Radiation Hardened Compact multi-Channel DAC	NASA	FY 14	Radiation hardened, compact, low-power integrated circuit
Develop technologies to reduce costs and improve performance of satellite buses, payloads, and components	Advanced space structures	Integrated Structural Systems	AF-AFRL	FY 17	Transition to acquisition
	Next generation space electronics	Space Electronics Technology	AF-AFRL	FY 17	Transition to acquisition
	Robust M&S tools for tech assessment/investment decisions	Modeling, Simulation, Evaluation and Assessment	AF-AFRL	FY 17	Transition to operational use
	Integrated circuit thermal control	Chip Integrated, Hybrid EHD/Capillary Driven Thermal Management System	NASA	FY 15	Low mass, volume, and power consumption for electronics thermal management

Table 9 Space Enablers, cont'd

Improve key building blocks for future responsive space systems	Wirelessly-interconnected space craft modules for secure resource sharing	System F6	DARPA, NASA, Navy-NRL	FY14	Software and designs
	Flexible/adaptable satellite crosslink	Edison Demonstration of Small Networks (EDSN)	NASA	FY 14	Maintaining crosslinking for 8 CubeSats
	Ground system development	Goddard Mission Services Evolution Toolbox	NASA	Ongoing	Publication of standards
Improve tools for design and test of components and systems	Micro fabrication	Micro-Rapid Prototyping Project	NASA	FY 14	3-D fabrication of 500 µm parts
	Additive manufacturing	Additive Manufacturing Technology Development	NASA	FY 15	Proof-of-concept test on ISS
	Single piece construction	Advanced Manufacturing Technologies (AMT): Advanced Near Net Shape Technology	NASA	FY 16	Radically improve near net shape manufacturing methods
Develop disruptive technologies enabling transformational space capabilities (e.g. Carbon based nanotechnology)	Microsatellite testbeds for multi-body formation flight experiments	International Space Station SPHERES Integrated Research Experiments (InSPIRE)	DARPA, NASA, Navy-NRL	FY 15	Space flight demo

Table 9 Space Enablers, cont'd

	Carbon nanotube structures	Nanotechnology (NT): Carbon Nanotube Structural Materials	NASA	FY 16	30% reduction in launch vehicle mass
Develop ultra-high-efficiency power system components, such as solar cells, batteries, and adaptive point-of-load converters	Batteries, fuel cells, solar array systems and other power modules	AES Modular Power Systems	NASA	FY 14	Common, efficient power systems
	High specific energy storage	Advanced Space Power Systems (ASPS): Advanced Energy Storage Systems Project	NASA	FY 16	Li-ion battery cells to 350 Wh/kg and and the energy density to 3500 Wh/L
	Spacecraft energy efficiency	Steerable Spacecraft Radiator	Navy-NRL	FY 18	Space flight demo
	Space qualified solar cells	Advanced Inverted Metamorphic (IMM) Multi-junction Solar Cells	AF-AFRL	FY 18	33% efficient cells transitionable to acquisition
Maximize satellite dry mass reduction through game changing technologies	Metamaterial antenna	Metamaterial-Backed Conformal Antennas for Space Exploration	NASA	FY 15	Antenna design will decrease the size and weight
Develop next generation space qualified focal planes	Focal plane development	High Resolution Mid-wave Infrared	AF-AFRL	FY 18	Space flight demo

Table 9 Space Enablers, cont'd

Long Term S&T Goals	Focus	Project Name	Service/Agency	Completion	Key Metric
Improve ultra-high-efficiency power system components, such as solar cells, batteries, and adaptive point-of-load converters	Space energy novel systems	Photovoltaic RF Converter Antenna	Navy-NRL	FY 22	Space flight demo
Maximize satellite dry mass reduction through game-changing technologies	High-density memory and processing	Space Electronics Technology	AF-AFRL	FY 22	Space qualification of chips
Develop technologies that facilitate integrating U.S. architectures with international and commercial partner systems and technologies	Real-time data fusion and dissemination	Inter-operable Architecture for Sensor Webs	NASA	Ongoing	Increase in number of participating sites